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GAS TURBINE AND JET ENGINE FUELS

PROGRESS REPORT NO. 1

NAVY BUWEPS CONTRACT NOw63-0406-d

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PHILLIPS PETROLEUM COMPANY - RESEARCH DIVISION REPORT 3559-63R
Feature No. 6058
August 5, 1963

Progress Report No. 1
Navy BuWeps Contract NOw63-0406-d
GAS TURBINE AND JET ENGINE FUELS

By

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SUMMARY

Twelve-hour metal loss tests on the combined effects of fuel sulfur and ingested sea water (so-called "black plague" corrosion conditions) on turbine inlet guide vanes using the Phillips 2-Inch Research Combustor have been completed during the first quarterly period, April through June 1963, under Navy BuWeps Contract NOw63-0406-d. Five typical superalloys including Udimet 500, Waspalloy, Haynes Alloy 25, Hastelloy R-235 and Rene' 41 were evaluated. An essentially sulfur-free base fuel consisting of 75 per cent (wt.) JP-5 boiling range isoparaffins plus 25 per cent (wt.) cumene was contaminated with 1 per cent (wt.) sulfur (as ditertiary butyl disulfide). Time was available for only a single comparative test (Udimet 500) on the isoparaffinic fuel with 1 per cent sulfur but no aromatic added.

The results obtained show that (1) from the single set of comparative test results available the presence of 25 per cent (max. specification limit) aromatics in the base fuel had no detrimental effect on metal durability at 2000 F; (2) ingestion of sea salt at the level of 15 parts per million of the total mass throughput to the combustor (a rate realistic, for example, for helicopters hovering just above the ocean surface) dramatically increased metal loss rates for all the alloys above the rates observed during operation on a 1 per cent sulfur fuel without sea salt ingestion.

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PHILLIPS PETROLEUM COMPANY

BARTLESVILLE, OKLAHOMA

Progress Report No. 1
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I. INTRODUCTION

Twelve-hour metal loss tests on the combined effects of fuel sulfur and ingested sea water (so-called "black plague" corrosion conditions) on turbine inlet guide vanes using the Phillips 2-Inch Research Combustor have been completed during the first quarterly period, April through June 1963, under Navy BuWeps Contract NOw63-0406-d. Five typical current-generation superalloys, including Udimet 500, Waspalloy, Haynes Alloy 25, Hastelloy R-235 and Rene' 41 have been evaluated. An essentially sulfur-free (< 10 ppm total sulfur) JP-5 boiling range isoparaffinic fuel was blended with 25 per cent (wt.) cumene to provide a base fuel with maximum specification limit aromatics content to which was added 1.0 per cent sulfur as ditertiary butyl disulfide. The cumene was included in the fuel to maximize the formation of carbon and thus provide conditions favorable for local reduction of protective chromium oxide films, as discussed previously in (1). During this reporting period time has been available to complete only one test (with Udimet 500) under otherewise the same conditions but without cumene in the fuel. However, this does provide some indication of the effect of the added aromatics. The results of these tests will be compared with those reported in (1) in which sea water ingestion was not included.

II. TEST METHODS AND APPARATUS

The Phillips 2-Inch Research Combustor and associated equipment used in preparing the combustion-gas-exposed simulated turbine inlet guide

vane specimens have been described in (2). Some exploratory "black plague" turbine inlet guide vane corrosion tests were attempted with this combustor operating on a 1.0 per cent sulfur fuel containing 25 per cent (wt.) aromatics. Sea water was injected, thus completing the environment of sulfur dioxide, sea salt, and reducing carbon. These tests were run under cyclic conditions simulating a sea-level tactical fighter mission consisting of 600 miles at Mach 1.2 and 200 miles at Mach 2.2. Specifically the combustor operating conditions chosen for these tests were as follows:

		2-Inch Combustor Operating Conditions				
Cycle	Flight Conditions Simulated	P, in Hg abs.	V, Ft./ Sec.	Inlet Air Temp., °F	Exhaust Gas Temp., °F	Duration, Minutes
1	300 Miles Sea Level Cruise to Target Area at Mach 1.2	350	200	900	1550-1600	20
2	200 Miles Sea Level Supersonic Dash Over Target Area at Mach 2.2	450	200	1200	1950-2000	10
3	300 Miles Sea Level Cruise Return to Base at Mach 1.2	350	200	900	1550-1600	20
4	Deceleration, Landing and Shutdown	350 350	200 100	900 900	900 900	5 5

The intention was to repeat this sequence six times for a total test duration of six hours or six simulated missions. Attempts to operate the existing Phillips 2-Inch Research Combustor under the very severe conditions of Cycle 2 resulted in melting and subsequent catastrophic failures of combustor liners. Various simple changes, such as adjustment of cooling air port sizes, were tried without success. This was followed by several tests at a compromise inlet air temperature of 1100 F in an attempt to alleviate the obvious cooling problem. These tests produced varying results ranging from failure at the end of the first complete sequence to failure at the end of five sequences.

At this point it became clear that the existing combustor design was not satisfactory for operation under the above conditions. Further attempts to operate under these conditions were suspended and combustion redesign studies were initiated. Evaluations of several new designs have yielded promising results in short duration trials. Two of the flame tube configurations employing "splash cooling" will undergo endurance testing in the near future.

In the meantime, in order to generate some information on "black plague" corrosion while awaiting completion of the development of these new designs, a series of tests has been completed operating under compromised combustor operating conditions of P = 350 in Hg absolute, V = 100 ft./sec, IAT = 900 F and EGT = 1950-2000 F.

Simulated turbine inlet guide vanes were placed, as shown in Figure 1, at a position approximately six inches downstream from the combustor section. These vanes were fabricated from the five superalloys described in Table I. The duration of exposure of each pair of specimens was twelve hours, obtained by running six two-hour intervals. After each two-hour period the specimens were cathodically descaled in molten sodium hydroxide for a period of ten minutes at a current density of 2.5 amperes/in.^{2} and then reweighed. The data are reported as milligrams of accumulated metal loss (both strips) per square centimeter of exposed area.

Synthetic sea water was injected directly into the primary zone of the combustor at the rate of 365 parts (by weight) of synthetic sea water per million parts of combustor total mass throughput (air + fuel) or 15 parts of sea salt per million parts of mass throughput. The synthetic sea water formulation used was that described in ASTM Method D 665-60. Components and concentrations were as follows:

Component	Concentration, grams/liter
NaCl	24.54
$MgCl_2 \cdot 6H_2O$	11.10
Na_2SO_4	4.09
$CaCl_2$	1.16
KCl	0.69
$NaHCO_3$	0.20
KBr	0.10
H_3BO_3	0.03
$SrCl_2 \cdot 6H_2O$	0.04
NaF	0.003

Data previously reported (1) on metal durability during exposure to 2000 F combustion gases derived from burning a 1.0 per cent sulfur fuel but with no ingestion of sea water are included herein for comparison with present data.

III. DISCUSSION OF EXPERIMENTAL RESULTS

The metal loss data obtained during this reporting period on corrosion of simulated turbine inlet guide vanes operating at 2000 F EGT under "black plague" conditions (fuel sulfur contamination plus ingested sea water) are shown in Table II and also as functions of test duration in Figure 2. Considering first the effect of adding 25 per cent (wt.) cumene to the base fuel in order to make conditions favorable for carbon formation and possible subsequent reduction of protective chromium oxide films, examination of the two tests on Udimet 500 shown in Table II indicates that the aromatic brought about no acceleration of metal loss rate above that observed when the JP-5 boiling range isoparaffinic fuel was used alone (note 1 per cent sulfur was present in the fuel and 15 ppm of sea salt was injected during both tests).

Although data on the effect of added aromatics are available only from tests on Udimet 500, there is the suggestion of little, if any, effect. Additional data will be obtained using other alloys, but at this time a comparison of the corrosion data shown in Table II obtained under "black plague" conditions with those obtained using 1 per cent sulfur fuel (no aromatics) but without sea water ingestion seems justified. These latter data were reported previously in (1). This comparison is shown graphically in Figure 2.

Figure 2 shows quite dramatically the profound effect of the ingestion of sea water on all five of the superalloys used in the program. Metal loss rates rose by a minimum factor of about five with Waspalloy to as much as 35 with Haynes Alloy 25, although the highest metal losses were experienced with Hastelloy R-235 and Rene' 41. Additionally, it will be noted that both Hastelloy R-235 and Rene' 41 demonstrated definite deviations from the linearity observed with the balance of the alloys. Interestingly, this linearity of metal loss vs. time was retained by Haynes Alloy 25, Udimet 500 and Waspalloy during the tests in which sea water was ingested. The performance of Rene' 41 was unique in that a major portion of its weight loss occurred at the beginning of the test. No ready explanation of this performance by R-41 is available. The marked acceleration of loss with HR-235 as compared to the other alloys conforms in trend with results reported by others, (3) with alloys containing 15 per cent or less chromium in sea salt exposure at elevated temperatures and is also consistent with the relative performance of this alloy without sea water present.

IV. CONCLUSIONS

An exploratory series of laboratory combustor tests on so-called "black plague" corrosion of typical turbine blading materials under conditions

simulating ingestion of relatively large amounts of sea spray and operation on a fuel containing 1.0 per cent sulfur have shown that:

1. Limited data indicates that the presence of 25 per cent aromatics in the base fuel had no detrimental effect on metal durability at 2000 F.
2. Ingestion of 15 parts of sea salt per million parts total mass throughput to the combustor dramatically increased metal loss rates for all the alloys above the rates observed during operation on a 1 per cent sulfur fuel without sea salt ingestion, confirming by actual combustor tests, the reported catastrophic furnace test results of "black plague" corrosion.

V. OUTLINE OF PLANNED FUTURE EFFORTS

During the second quarterly period under Contract NOw63-0406-d it is planned to carry on endurance tests on two promising new combustor designs capable of operating at a combustor pressure of 450 in Hg abs, an inlet reference velocity of 220 ft./sec., an inlet air temperature of 1200 F and sufficient fuel input to achieve 2000 F exhaust gases. These conditions are designed to simulate sea level operation of regenerative turboshaft engines in either submarine search aircraft or helicopter applications. If, as expected, a successful design emerges from these endurance runs it is planned to begin a program of turbine guide vane durability testing under these advanced severity conditions varying fuel sulfur content and fuel aromaticity with sea salt ingestion constant at the rate of 100 parts per million parts of total mass throughput.

REFERENCES

1. Streets, W. L. and Schirmer, R. M.; "Gas Turbine and Jet Engine Fuels", Summary Report, Navy BuWeps Contract N600(19)-58219, Phillips Research Division Report 3529-63R, July 1963.

2. Fromm, E. H.; "Design and Calibration of the Improved Phillips Jet Fuel Testing Facilities", Phillips Research Division Report 3527-63R, July 1963.

3. Anonymous; "Sulfur Attach on High Temperature Turbine Materials", prepared by Bristol-Siddely Engines, Ltd., presented before the Thirteenth Technical Conference, International Air Transport Association, Lucerne, May 1960, Agenda Items 6 and 11.

TABLE I

COMPOSITION OF ALLOYS USED IN TURBINE GUIDE VANE METAL LOSS TESTS

Alloy	Per Cent by Weight of Indicated Metal																
	Cr	W	Fe	C	Si	Co	Ni	Mn	Cb	Mo	P	S	Al	Ti	B	Zr	Cu
Udimet 500*	19.0	—	.36	.09	.15	18.7	51.04	<.10	—	4.35	—	.005	3.10	2.99	.003	<.01	<.10
Waspalloy*	19.5	—	.95	.053	.03	13.2	57.44	.01	—	4.41	.003	.003	1.23	3.10	.002	.06	.01
Haynes Alloy 25	20.0	15.0	3.0	.1	1.0	Bal.	10.0	1.5	—	—	—	—	—	—	—	—	—
Hastelloy R-235*	15.29	—	9.96	.15	.26	.38	63.91	.03	—	5.48	.001	.009	2.05	2.48	—	—	—
Rene' 41*	18.33	—	1.90	.10	.16	10.69	54.37	.05	—	9.69	—	.009	1.54	3.15	.005	—	—

* Specific analyses for particular samples tested in combustor. Values shown for other alloys are typical compositions.

TABLE II

TURBINE GUIDE VANE "BLACK PLAGUE" CORROSION TESTS IN PHILLIPS 2-INCH COMBUSTOR

Combustor Operating Conditions: P = 350 in Hg abs.; V = 100 ft./sec.; IAT = 900 F; EGT = 1950-2000 F

Guide Vane Alloy	Test Fuel	Sea Salt Input, ppm*	Accumulated Metal Loss, mg/cm^2					
			2 Hr.	4 Hr.	6 Hr.	8 Hr.	10 Hr.	12 Hr.
Udimet 500	75% (wt.) JP-5 Type Isoparaffinic Alkylate 25% (wt.) cumene w/1% (wt.) Sulfur (as ditertiary butyl disulfide)	15	7.5	26.2	35.7	49.7	62.4	90.5
Udimet 500	100% (wt.) JP-5 Type Isoparaffinic Alkylate w/1% (wt.) Sulfur (as ditertiary butyl disulfide)	15	3.3	17.8	36.6	58.3	79.0	109.5
Waspalloy	75% (wt.) JP-5 Type Isoparaffinic Alkylate 25% (wt.) cumene w/1% (wt.) Sulfur (as ditertiary butyl disulfide)	15	1.4	9.2	20.8	30.8	45.2	63.7
Haynes Alloy 25	Same as Above	15	9.9	25.4	50.0	83.0	97.2	110.4
Hastelloy R-235	Same as Above	15	5.2	19.9	51.8	108.0	181.6	239.4
Rene' 41	Same as Above	15	54.9	65.5	79.2	90.5	107.8	148.4

* The sea salt input shown is in parts of sea salt per million parts total combustor mass throughput.

The sea salt input shown is equivalent to 365 ppm of sea water.

HOLDER MAT'L: 310 SS; STRIP MAT'L.: VARIOUS TURBINE BLADING ALLOYS
SCALE: 1" = 1"

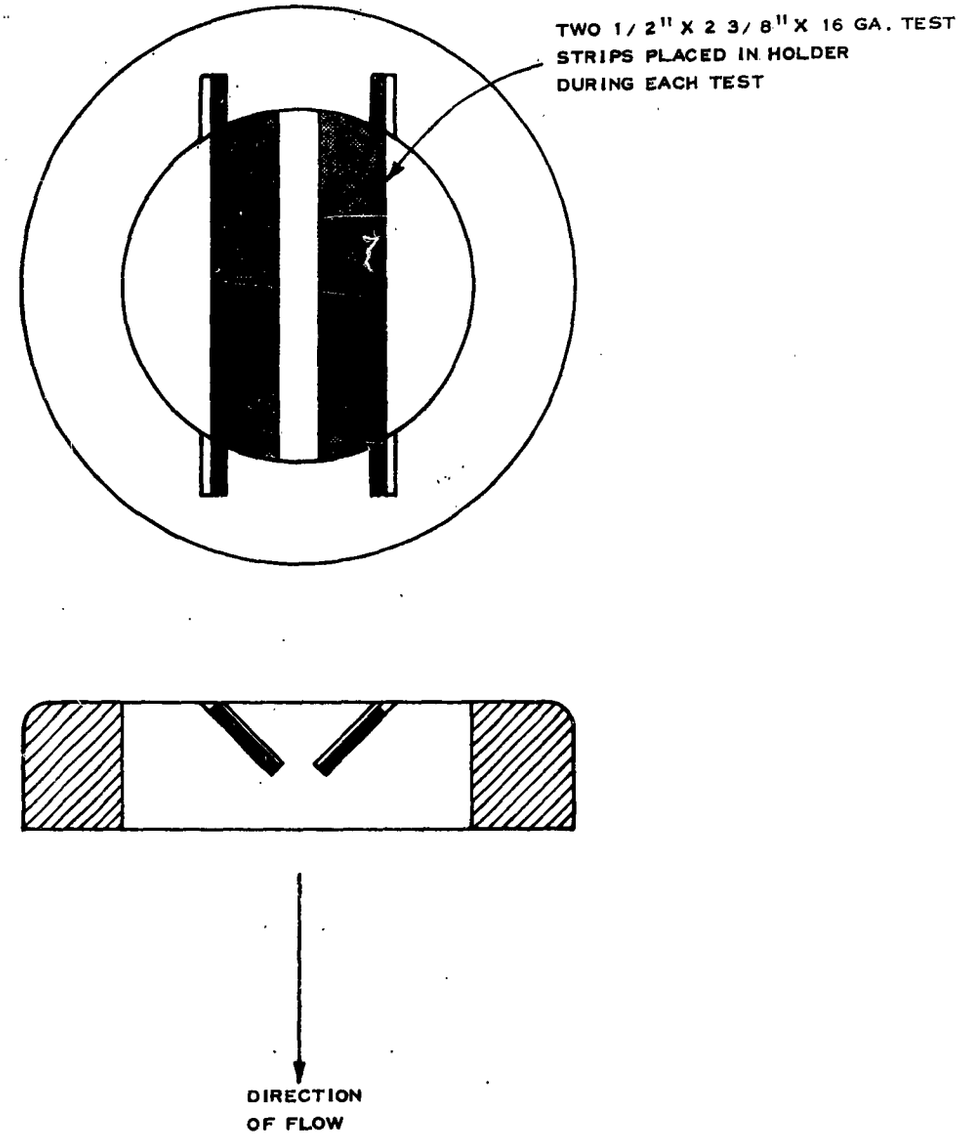

FIGURE 1
SPECIMEN HOLDER FOR PHILLIPS 2-INCH COMBUSTOR SIMULATED
TURBINE INLET GUIDE VANE DURABILITY TESTS

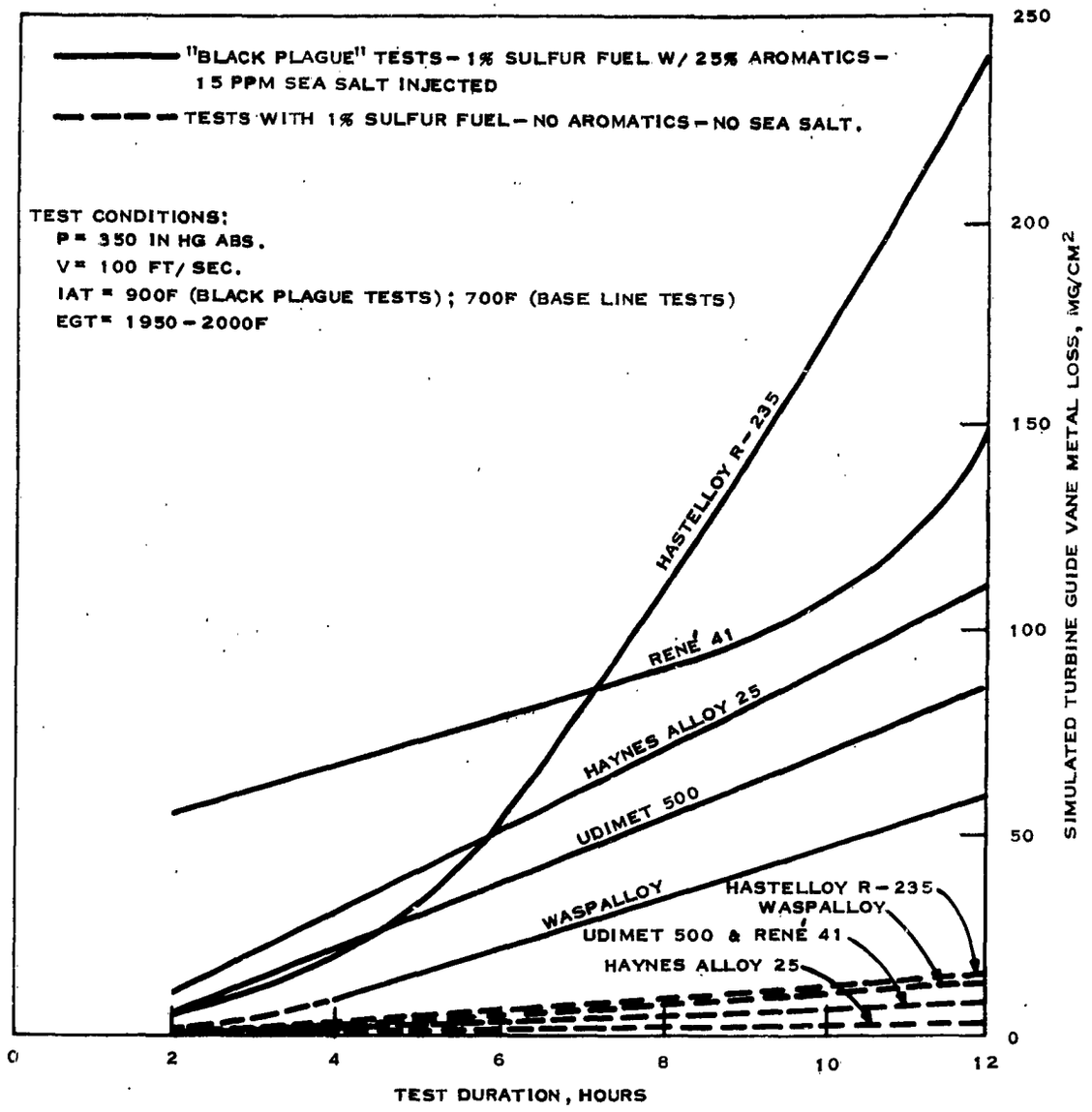

FIGURE 2
TURBINE GUIDE VANE METAL LOSS AS A FUNCTION OF TEST DURATION
FOR EXPOSURE TO SULFUR AND/OR SEA SALT LADEN ATMOSPHERES